ROYAL HOLLOWAY AND BEDFORD NEW COLLEGE
UNIVERSITY OF LONDON

DIELECTRIC SPECTROSCOPY OF SEMICONDUCTORS

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Professor Andrew K Jonscher
Dr Mohammad A Bari

ABSTRACT

Work in the reporting period was concerned with gaining an improved understanding of the processes in high-resistivity semiconductors and also with the elucidation of the highly intriguing but not yet clearly understood behaviour of two-dimensional electron gas in a nearly-cut-off FET. We report progress in both these areas.

INTRODUCTION

Theoretical Interpretation

Our understanding of the dielectric responses of semiconductors is advancing as a result of recent developments under the present Contract devoted to the study of the Dielectric Spectroscopy of Semiconductor (DSS). Our theoretical model based on the concept of "screened hopping" outlined in the Second Progress Report appears to us to provide a sound and self-consistent basis for the interpretation of the experimental results obtained in our long involvement with the study of the dielectric properties of semiconductors. There exists at present no other accepted or, indeed, proposed theory of these phenomena, and we attribute this lack of theoretical models to widespread ignorance on the part of Physicists of the Solid State of even the existence of the experimental data pertaining to the dynamics of electronic transitions as manifested by DSS. It is regrettable, therefore, that these theoretical ideas have met with some negative Referee opinions which have delayed their publication by several months – opinions not supported by specific objections other than that the theory is "qualitative", which is an objection that could be raised with respect to *all* dielectric theories. The most recent Referee reports for another Journal are much more encouraging.

Fundamental to the new model is the concept of partial screening of localised charge carriers by other charges in neighbouring localise states. The availability of such states is therefore critical in determining the magnitude of the loss and therefore also of the exponent in the "universal" power-law of dielectric response. Materials with few localised levels are expected to have low losses and correspondingly "flat" frequency dependence of the loss and susceptibility. This is generally confirmed in the case of devices made on very high-resistivity silicon, as those described in the 3rd Progress Report. However, our measurements have revealed some unexplained loss processes which we have just checked are not experimental artefacts.

Low–Dimensional Electron Gas

A second fundamental theoretical problem arising from our study reported in the 3rd Progress Report is the frequency dependence of the conductance of a nearly–cut–off channel in a field-effect transistor (FET). We have predicted that there should be such frequency dependence because of the anticipation that the flow of current in such a two-dimensional electron gas should be *filamentary* rather than uniformly distributed over the area of the channel. There is no rigorous *á priori* justification for either of these assumptions, but our measurements have shown that a distinct frequency dependence was, in fact, observed in the case of one particular FET type.We were not satisfied, however, that the measurements on other FETs were wholly consistent with the initial observations, and only now are we able to report that there is, indeed, a definite frequency dependence, but in some cases this tends to be overshadowed by a parallel direct current conductance which is independent of the gate bias. We are now able to resove these two components and the clear tendency for the frequency-dependent component is to follow the half-power law $G(\omega) \propto \omega^{1/2}$. This is different from the anticipated dependence in which the exponent of the power law was to be smaller,and it is very likely that this result is a consequence of the distributed "transmission line" effect between the gate capacitance and the fairly high channel resistance. The conclusion from this is that the observation of the expected effect depends on the fulfilment of certain conditions which are elusive as yet.

EXPERIMENTAL RESULTS

a) FET data.

The dielectric response of Field Effect Transistor type BS 170, which has a higher power handling capacity than the device described in the 2nd Progress Report, shows a clear frequency dependence but only after subtraction of a relatively high direct current (dc) conductivity contribution G_0/ω from the loss components. The Kramers-Kronig-compatible fitting of the experimental data is made by first subtracting a suitable value of "high-frequency" capacitance C_∞ from the real part and subsequently fitting the loss data. The results of this operation are shown in Figure 1 and they give clear slope –1/2 which corresponds to the classical transmission line model, although the *situation is rather* more complicated and we are currently undertaking a detailed analysis of this problem.

There is a fair amount of scatter in the results , but this is understandable in view of the subtraction of rather large numbers. A more serious difficulty arises because of the strong non-linearity of the system with respect to the magnitude of the source-drain voltage V_{DS}, arising from two causes:

a) the non-linearity of the drain-source current, I_{DS} against V_{DS}, especially close to the pinch-off condition where we have to operate in order to produce a weakly conducting channel.

b) The non-linearity with respect to the reversal of the polarity of V_{DS}, which implies that the steady bias V_0 should ideally be larger than the amplitude of the alternating voltage signal V_1. We are not able to satisfy the second condition in all cases and this may require a more detailed analysis.

The dependence of *the* G_0 *and* C_∞ on the steady bias V_0 is given in Table I.

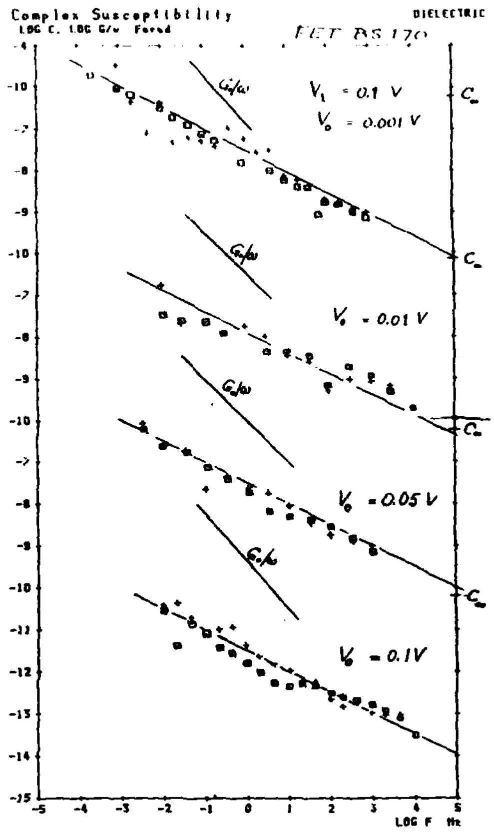

Figure 1. The dielectric response of a FET type BS 170 plotted as the differences $C(\omega) - C_{\infty}$ and $(G - G_0)/\omega$, where C_{∞} and G_0 are defined in text. The values of the steady bias V_0 are shown, the signal amplitude is in all cases $V_1 = 0.1$ V. The values of C_{∞} and G_0/ω are shown on the individual plots which are displaced vertically by four decades for clarity.

Table I

V_0 Volts	G_0 nS	C_{∞} pF
0.001	0.092	60.55
0.01	0.192	61.3
0.05	0.607	62.9
0.1	3.16	65.1

The somewhat surprising result is the fact that the data for the different bias conditions all fall into a very narrow range, as may be seen from the crossover of the extrapolated lines with the vertical axis. A fuller elucidation of this feature will have to await the detailed analysis of the FET situation.

In comparison with the low-power, low-noise FET 2N4092 reported in our 3rd Progress Report for July 1988 which was a clear case of Low-Frequency Dispersion expected in a two-dimensional electron gas, the present result correspond to a classical distributed line response of relatively smaller intrinsic interest.The implication is that the conductance of the channel must be very low, so that the interaction of the channel-gate capacitance with the high channel resistance dominates any inherent relatively weak frequency dependence of the channel conductance itself. Somehow, the earlier data on 2N4092 were not limited in this way.

This work will be continued because we believe that it is of significance to the understanding of two-dimensional electron gas conduction.

b) High-resistivity diodes

We have repeated the measurements on a high-resistivity diode reported originally in our 3rd Progress Report, where we have noted the sudden unexpected onset of a loss process between 150 and 200K. The results confirm in broad outline the earlier data and suggest a rapid onset of a specific loss process at around 200K. A characteristic features of this process is an unusually broad loss peak, for a p-n junction, which has a high-fequency slope with the exponent $n = 0.50$ of a type seen in other situations.

The very broad loss peak, corresponding to *small* values of the low-frequency exponent m represents an important contribution to the knowledge of the behaviour of "dipole-like" responses in semiconductors, which we are trying to understand more fully.

The diode in question shows another often observed feature - a "coupling" between the transition from the high-frequency loss to the dc process dominating at lower frequencies. This transition occurs consistently at the frequency at which the loss is equal to the real part of the capacitance - something which we are unable to understand at present, but which is clearly significant for the understanding of the trapping processes in semiconductors.

This point will be considered in more detail in the near future.

FUTURE PLANS

We intend to continue the studies of FETs in the nearly-cut-off condition, because of the importance of the understanding of two-dimensional electron gas flow.

We will continue looking onto the loss processes in high-resistivity diodes, which shows important features for the understanding of trapping processes.

It is regrettable that we are finding it very difficult to obtain good samples for measurements, despite repeated requests of our suppliers.